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Oxyfuel Optimization using CFD Modeling

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Abstract

Before converting production furnaces to different combustion technologies it is essential to understand all related changes and side effects. An experienced team will be able to successfully conclude a conversion like this. However, CFD modeling will enable to make informed decisions in terms of effort and results of furnace retrofitting with new combustion equipment. This paper will give insight of how oxyfuel together with CFD can impact energy balance and productivity of production furnaces.

Introduction

Aluminum recycling and re-melting is a very competitive industry area. Global markets and globalization of aluminum melting technologies and aluminum trade brushes up the dust in every corner of the business. Aluminum producers with large melting furnaces are constantly under pressure to bring production cost down and hence to use the latest available technology. Any change is associated with risks. Furnaces with larger production capacities face higher risk as compared to small ones. Being able to estimate process changes before capital money is spent allows to even optimize a technology towards temperature and heat profiles as well as productivity and energy usage before the system is build.

Basic Elements

A melting operation consists of various specific elements that need to be transferred into the computer model. However not all can be transferred and not all can be modeled. Hence the model will only be a model and not real. Aspects like charge material quality, quantity, composition and mixtures are very difficult to describe in a model. Charging material storage and altering process conditions as well as the melting itself with all changing physical properties are hard to specify and model. The combustion space of a furnace can be modeled with justifiable effort. The system of the combustion space then needs to be defined and described well enough to come to reasonable results that can reflect the reality. The model will preferably describe steady state conditions, i.e. altering firing rates and flame shapes cannot be characterized in one single step. The model needs to be connected to reality and will need to be verified with the current operation.

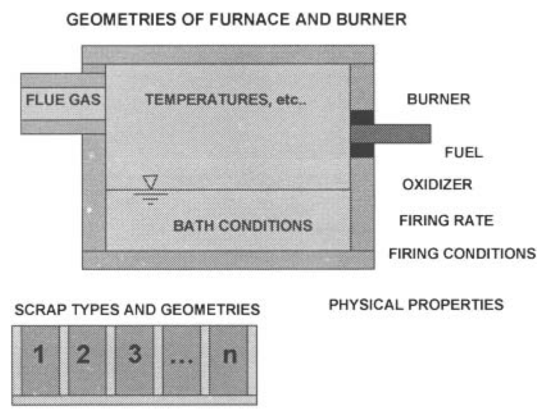

Figure 1: Basic elements of aluminum melting process.

Model Set Up

The melting or heating operation to be modeled typically consists out of a specific furnace geometry (rotary furnace, reverberaotory furnace, tower furnace, shaft furnace and many more). This furnace geometry together with refractory material, flue openings, burner positions and geometries, bath level and other protruding elements define the combustion space. Geometries, thicknesses, and physical properties of the materials then are put together to the model. The mesh size of the model describes how detailed the combustion process will be described in a specific location of the model. The mesh size can vary across the furnace. Typically it needs to be very small (detailed) where rapid changes in either geometry or chemistry is expected. The mesh is refined near the region of the burner to capture the gradients effectively. Homogenizing with slow dynamics areas will have wider mesh sizes, when there is an expectation of reduced activity. A typical aluminum reverberatory furnace model with a capacity of 30 t and a footprint of 450 sqft (50 m2) will have 500.000 knots with an average distance of ½ foot (0.15 m). Where each knot represents that all equilibrium equations (heat, energy and mass) will be solved. The model works its way through the furnace system by moving from knot to knot. It can take days or weeks to simulate one single steady state operating point in a way that the results make sense and are good enough for verification. Recent advancements have enabled to solve the governing equations in parallel using multiple CPU's which reduces the computing time significantly.
Typical combustion systems involve high speed flows. Hence choice of proper turbulence models is very important to predict the solution accurately. In most of the cases, reaction is mixing controlled hence turbulence chemistry interaction needs to be

resolved correctly to accurately predict the flame shape and temperature distribution. Also as high temperatures prevail inside the furnace, radiation heat transfer plays significant role in transferring energy from the combustion space to the metal bath. Hence choice of the radiation model will also play a vital role in the accuracy of the solution.

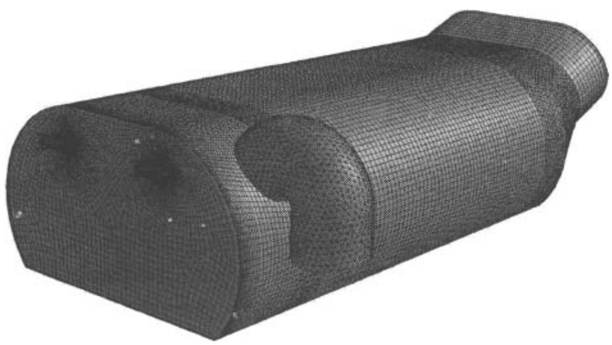

Figure 2: Example of mesh size and geometry.

Combustion System

The combustion system is a very complex system of geometries, kinetics and chemical reactions. When modeling the modeler has to decide which condition to model and why. Very often typical and characteristic operating conditions are being modeled. Like high temperature intervals when looking at specific heat transfer and temperature profiles. Flame shapes and sizes for refractory investigations. NOx and CO profiles for gaseous emissions from combustion processes.

CFD in Aluminum Melting

Traditional cost intensive CFD modeling has been used for major furnace projects, where the modeling cost was only a fraction of the capital investment. The simulation was used to make informed decisions about heat transfer, temperature profiles, emissions, burner and flue locations and efficiencies/cost. Large capacity steel making plants, power plants and large scale glass plants have been using CFD modeling for a long time and have good experience in getting useful results for decision making processes. In aluminum and metals melting and recycling there are only few examples how and where CFD is being used. The Linde Group has put effort in understanding and detailing combustion processes with CFD for melting of metals like aluminum and copper.

Examples

By simulating combustion processes the effects of different flame shapes can be analyzed and compared. Conventional oxyfuel is often regarded as pipe in pipe and round flame geometries (Fig. 3). The flat flame of an oxyfuel burner is shown in Fig. 4.

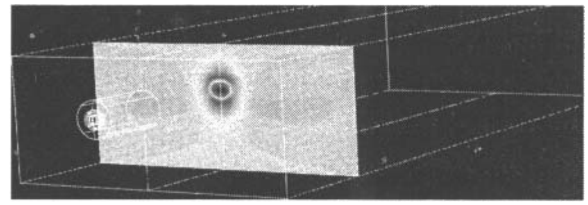

Figure 3: Conventional and round oxyfuel flame and combustion space temperature profiles.

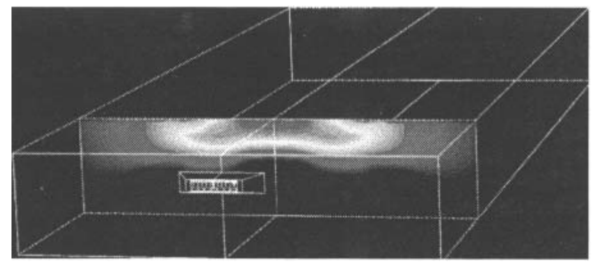

Figure 4: Flat Jet oxyfuel burner flame and combustion space temperature profiles.

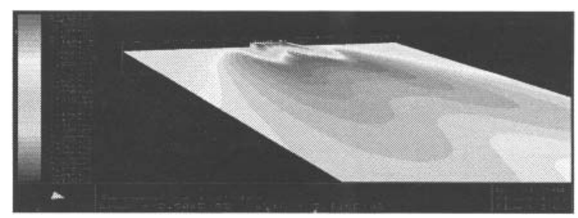

Figure 5: Flat Jet oxyfuel burner flame and combustion space temperature profiles.

By comparing such different flame specific characteristics in one single furnace geometry there will be differences in heat transferred into metal bath area and towards the walls. When changing burners and/or burner locations and comparing the effects to the metal bath and the walls will lead to and optimization process without fining the new combustion system.

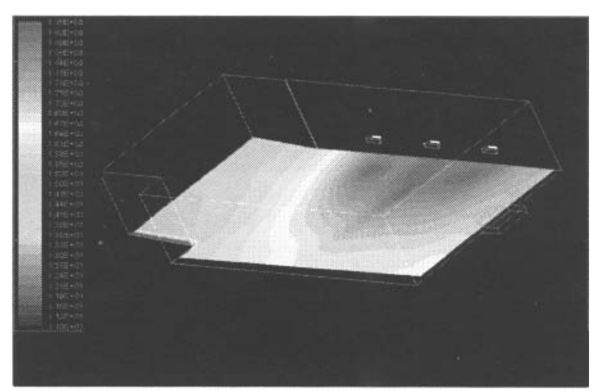

Figure 6: Example of temperature profile above metal bath level.

Air fuel operated combustion processes for melting aluminum has benefits and disadvantages that are listed below:

Benfits:
- Low flame temperature
- No oxygen cost
- Good convective heat transfer
- Slow reactivity

Disadvantage:
- High gas volumes
- High energy demand
- Low efficiency
- Noise emissions
- Dust emissions

Linde has developed a combustion technology that combines the advantages of air fuel combustion by avoiding the disadvantages at the same time. This technology was developed from the need of the aluminum industry to avoid local overheating and hence reduce oxidation of the metal. The Linde response is low temperature oxyfuel combustion technology. The low temperature oxyfuel combustion process combines the benefits of air fuel and oxyfuel combustion process. This means the low flame temperature and high convective heat combined with high energy efficiency from oxyfuel. CFD modeling is used to describe and evaluate the changes that oxyfuel would bring in such a situation. The experience from converting to oxyfuel at a casthouse from Hydro Aluminium in Norway has been described in /1/. There an oxyfuel burner has been used to compensate hot pot room metal with ambient temperature solid scrap. This is an example of how oxyfuel lifts existing limits and borders to the next level.

These days the analysis of combustion processes especially in the aluminum area focus on highly efficient heat transfer without local over heating. Comparing various oxyfuel cases leads to the following conclusions:

- oxyfuel and oxyfuel can be different
- flame shape and volume are important
- flame temperatures matter
- furnace gas recirculation has an impact on heat transfer

When evaluating all these different parameters – oxyfuel can be optimized versus oxyfuel. The next exciting question is: How does optimized oxyfuel compare to regenerative pre heated air fuel operation? Here linde has done extensive research to better understand the specifics and details that are important to keep all benefits from air fuel firing and all benefits from oxyfuel firing.

Figure 7 shows a comparison of a regenerative air fuel fired furnace with a low temperature oxyfuel (LTOF) fired case.

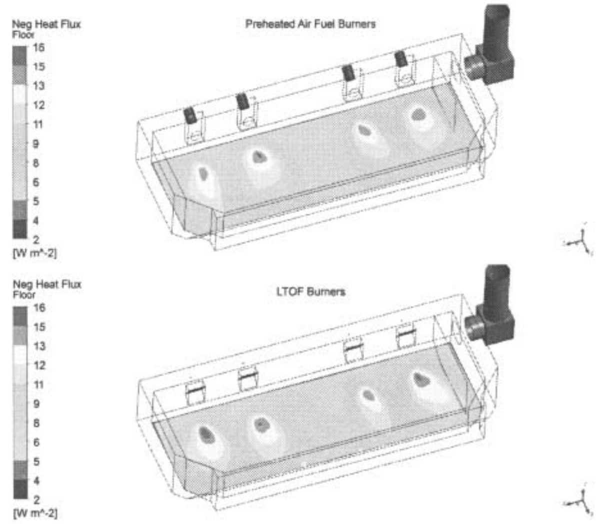

Figure 7: CFD comparison of temperature contours of pre heated air fuel burners and oxyfuel burners in a reverberatory furnace.

In other publications /2/, /3/ and /4/ the energy and emission impacts of oxyfuel in comparison to air fuel are described. CFD modeling does reflect these changed conditions and helps to get a better and deeper understanding.

Summary

CFD Modeling has shown to have many benefits and it avoids the often applied "trial and error" approach. It can also be used to maximize oxyfuel benefits and minimize emissions. The Linde Group is pioneering the way into CFD modeling for non ferrous metals melting in combination with oxyfuel combustion technologies.

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